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WAVE LENGTHS IN THE RED AND INFRA-RED SPECTRA OF IRON, COBALT, AND NICKEL ARCS

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I. INTRODUCTION

The scarcity of accurate data for wave lengths longer than those of yellow light has led the Bureau of Standards to make extensive application of photographic sensitometry to the study of long wave-length regions in the spectra of chemical elements. Wave-length measurements in spectra from 5600 A to 9600 A[1] have been published for 11 of the chemical elements, viz, lithium, sodium, potassium, rubidium, caesium, copper, beryllium, calcium, strontium, barium, and magnesium. The wave lengths in the arc spectra of iron, cobalt, and nickel, presented in the present paper, represent further investigations in standard wave lengths and spectrum analysis. It was thought especially desirable to know to what extent photographic methods with a large diffraction grating are applicable to the infra-red spectral regions. Furthermore, it was hoped that investigations of this kind would lead to the discovery of some spectrum which is more satisfactory than that of the iron arc for standard wave lengths in the red and infra-red. Before such standards can be accurately measured by interferometer methods it is necessary to have the approximate values represented by measurements from grating spectra. The values given below represent the long waves of iron, cobalt, and nickel to the extreme limit which it is practicable to reach with our apparatus and photographic method.

[1] This Bulletin, 14, p. 371; 1917.

II. APPARATUS AND METHODS

The spectral regions studied were photographed with a concave grating spectrograph which has already been described.[2] The source of light was the electric arc of the type recommended by the international wave-length committee.[3] The iron electrodes were of Norwegian or of electrolytic iron; those of cobalt were cut from an anode which contained not over 4.2 per cent impurities, chiefly iron, nickel, and carbon. Small lumps of "pure" fused cobalt obtained from Eimer and Amend were burned in an Acheson graphite arc for two of the spectrum photographs. Electrodes of nickel were cut from an anode which contained about 4 per cent of iron as well as small quantities of cobalt, copper, and a trace of manganese.

The photographs were made on Seed 27 plates which were made sensitive to the long waves by staining with pinacyanol, dicyanin, or dicyanin A. The preparation of the sensitizing bath has already been described.[4] It was found that each bath of dicyanin could be used five or six times before losing its effectiveness, while the pinacyanol could be used many times. Plates bathed in pinacyanol were used for the region 5500 A to 7000 A; for wave lengths greater than 7000 A the dicyanin or dicyanin A plates were used. Exposure times of 10 minutes sufficed to photograph the spectrum up to 7000 A; between 7000 A and 9000 A, 20 to 30 minutes exposure were sufficient; beyond 9000 A the exposure times ranged from 5 hours to 10 hours. The spectral region to be measured was photographed in the grating spectrum of the first order, with standard reference lines photographed adjacent, in either the first, second, or third orders, according to the region under investigation. During the exposures to the first order, the overlapping orders were absorbed either by a potassium bichromate cell or by a screen of Jena red glass.

The comparison spectra were photographed before and after the long exposures in the first-order spectrum so as to detect any shift due to temperature changes or displacements of the apparatus. In general, no appreciable shift was observed, even when exposures of 10 hours duration were made.

A few of the plates were measured on the measuring machine at the Johns Hopkins University. The remainder were measured on a large engine constructed by Gaertner and kindly loaned

[2] This Bulletin, **14**, p. 371; 1917.
[3] Astroph. Jr., **39**, p. 93; 1914.
[4] This Bulletin, **14**, p. 371; 1917.

to the Bureau of Standards by the Weather Bureau. The plates were measured directly in the sense increasing wave lengths with increasing scale readings; that is, with the red ends to the right, and then in the reversed position, with red ends to the left. From two to six settings were made on a line, and the mean of the readings was recorded as the scale reading for the line. In all cases the arc spectrum of iron served as the reference spectrum, and in the reductions the values of the wave lengths determined here [5] by interference methods were used. The probable errors in the wave lengths of iron, cobalt, and nickel given below are less than two or three hundredths of an angstrom in most cases where the line was measured two or more times. Lines indicated as having been measured only once may contain larger errors.

III. DESCRIPTION OF THE PLATES

Tables 1, 2, and 3 contain a description of the plates that were measured. In the first column is given the laboratory number of the plate; the second gives the region covered in the first order spectrum. In the third and fourth columns, respectively, are given the exposure times required and the slit widths used. In the fifth column is recorded the current strength, which was regulated to conform approximately to the region photographed. The sixth column contains the initials of the observers: M for Meggers and K for Kiess. "Observers" refers to the measurement and reduction of a plate as well as the securing of it. To Mr. Burka credit is due for assistance given in securing the plates for which long exposures were required.

TABLE 1.—Photographs of the Iron Spectrum

Plate No.	Region	Exposure	Slit width	Current	Observer
	A	Min.	Mm	Amp	
131	8400–10 400	30	0.05	6.0	M
208	7800– 9800	30	.....	7.0–8.0	M
214	7800– 9800	30	.04	8.0	M
221	6400– 8400	10	.....	.....	M
426	7800– 9800	120	.05	7.0	K
467	7800– 9800	360	.07	7.0	K
469	8400–10 400	600	.07	7.5	K
474	8600–10 600	600	.07	8.0	K
476	9400–11 400	600	.07	8.0	K
499(a) [a]	7000– 9000	30	.03	3.0	M, K
499(b) [a]	6400– 8400	15	.03	3.0	M, K
500 [a]	8200–10 200	360	.07	4.0	K
505	9000–11 000	420	.07	8.5	K

[5] This Bulletin, 13, p. 245; 1915.

[a] Electrolytic iron.

TABLE 2.—Photographs of the Cobalt Spectrum

Plate No.	Region	Exposure	Slit width	Current	Observer
	A	Min.	Mm	Amp	
129	8400–10 400	120	.....	7.0	M
197	6500– 8500	20	.....	7.0–8.0	M
206	7600– 9600	25	0.02	8.0	M
214	7800– 9800	30	.04	8.0	M
221 [a]	6400– 8400	10	.....	.....	M
224 [a]	5500– 7500	2	.....	.....	M
412	7000– 9000	25	.02	7.5	M, K
419	7600– 9600	120	.02	7.5	K
478	8400–10 400	330	.07	8.0	K
480	8800–10 800	390	.07	9.0	K
486	9400–11 400	600	.07	9.0	K
492	9700–11 700	420	.07	9.0	K
493	6000– 8000	30	.04	9.0	K
495	5500– 7500	20	.03	7.0	K
497	9700–11 700	480	.07	9.0	K

[a] E. & A. Co. in graphite.

TABLE 3.—Photographs of the Nickel Spectrum

Plate No.	Region	Exposure	Slit width	Current	Observer
	A	Min.	Mm	Amp	
209	7600– 9600	30	0.02	7.0	M
214	7600– 9600	30	.04	7.0	M
221	6400– 8400	10	.04	6.0	M
224	5500– 7500	2	.04	6.0	M
493	6000– 8000	30	.04	9.0	K
495(a)	7200– 9200	60	.04	9.0	K
495(b)	5500– 7500	20	.03	7.0	K
519	8600–10 600	405	.07	9.0	K
520	9000–11 000	480	.07	10.5	M

IV. RESULTS

In the final wave length Tables 4, 5, and 6 an attempt is made to give the arc spectra of "spectroscopically pure" iron, cobalt, and nickel. It is practically impossible to obtain metals that are absolutely pure and it is especially difficult to separate chemically the ferrous metals from each other and to prevent contamination by closely related elements such as copper, chromium and manganese. As far as possible, this separation is made spectroscopically in this work, by intercomparison of the intensities and wave lengths of all the lines observed in the spectra of these elements. Faint lines are considered as due to impurities whenever their measured wave lengths agree within the errors of observation with those of intense lines in the spectrum of a particular element. In some cases the relative intensities or the wave-length comparisons

do not seem to warrant the removal of the lines, so they are allowed to remain in the tables and marked as questionably belonging to some probable element present as an impurity. Some of these cases may represent coincidences of lines with approximately the same intensities and wave lengths in different elements but most of them are probably due to some unrecognized impurity contained in common by these elements.

Table 4 contains the iron lines measured in this investigation. The adopted wave lengths are, for the most part, the means of the values derived from two to six plates. Those wave lengths for which only one determination is available are specially indicated in the table. By using electrodes of electrolytic iron it was hoped to free the table from the lines of impurities. The spectrum of electrolytic iron was photographed from 6750 to 9118, and all lines in the table not measured in it are specially indicated. Beyond 9118 it was not possible to use the electrodes of electrolytic iron for the long exposures and at the current strength necessary. The lines in this region are those given by Norwegian iron. Most of the lines shorter than 9000 have been observed by Geiger,[6] or by Burns.[7] Those longer than 9000 are new. In his table Geiger gives four lines with wave lengths greater than 9000 A which he designates as doubtful. These lines as well as several more of Geiger's doubtful lines, shorter than 9000 A, were not measured on any of our plates. The intensities given in the second column of the table are included between the limits 1 and 10, intensity 1 indicating the weakest line capable of accurate measurement. After 10 000 A no intensities are assigned, as the photographic action of the lines is too weak to permit of relative estimates. Most of the lines representing the longer waves are near the limit of measurability when the plate is viewed through the measuring engine microscope which magnifies about six diameters.

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[6] Annalen der Physik, 4te Folge, 39, p. 782; 1912.

[7] Lick Observatory Bulletin, 8, p. 27; 1913.

TABLE 4.—The Arc Spectrum of Iron

[In the column headed "Remarks" the letters have the following significance: a=measured only once; b=broad; d=perhaps double; e=not measured in the spectrum of electrolytic iron; f=not given by Burns (6750 A to 8824 A); g=not given by Geiger (6750 A to 8999 A); h=hazy or diffuse; l=shaded to red; and v=shaded to violet)

λ I. A.	I	Remarks	λ I. A.	I	Remarks	λ I. A.	I	Remarks
6750.15	4		90.41	6	d	7389.43	7	
52.71	2		91.83	1	a, f, g	7401.71	2	
55.62	1	a, g	92.99	1	a, f	11.21	8	
86.94	2		7095.43	2		18.67	3	
93.32	1	a, g	7107.46	2		21.60	1	f
6796.06	1	a	12.17	2		30.73	1	b, f
6804.11	2	b	30.96	10		41.05	2	b, f
06.85	2	g	32.98	3		43.05	1	
10.27	3		42.55	2		45.80	9	
20.43	2	f	45.34	2	a	47.40	1	g
28.62	4		51.49	1	a, Mn?	53.98	1	a, e, g
37.00	1	f, g	55.62	2	a, g	61.55	1	
38.85	1		64.49	9		73.56	1	a, e, f, g
39.88	1	g	75.94	1		76.30	1	a, e, f
41.35	5		76.88	1	g	82.00	1	f
42.68	1	g	80.06	1	a, g	83.43	3	a, f, g
43.69	4		81.20	3	g	91.68	2	
55.15	6	l	81.94	1	a, Ni?	95.12	8	
57.23	1	g	87.36	10		7498.51	1	a, e, g
58.19	2		89.13	2	g	7507.32	2	
62.46	2	a	91.66	1	a, f	11.09	9	
85.78	4		7194.92	1	a	31.20	4	
6898.27	1		7207.41	10		46.18	2	
6902.84	1		12.47	1		59.68	1	a, f
16.72	4		19.70	2		63.03	1	f
33.59	2	a	21.23	1		68.94	4	a
45.22	7		23.66	.3		73.53	1	f
47.48	1		28.69	1	a	83.81	4	a
51.29	4		39.88	4		7586.08	7	
75.46	1	a	44.83	2		7605.32	1	a, f, g
77.42	1	a	54.62	1		20.54	3	
78.86	7		61.51	2	v	53.80	2	f
88.52	2		82.43	1		58.97	2	a, e, f, g
6999.92	4		84.83	2	l	61.24	3	
7000.56	1	g	88.79	4		7664.31	4	
08.02	2		93.01	6		7710.40	3	
10.33	1	g	7295.02	1		23.20	1	f
11.35	1		7300.47	2	a, b, e, f	42.71	1	a, f, h
14.99	1	a, f, g	06.60	2		48.30	4	
16.30	9	d (Burns gives two lines)	07.95	3		51.18	1	a, f
			11.13	4		7780.62	5	
22.98	5	d	20.72	3		7808.04	1	a, b, f
24.09	1	a, g	33.60	1		32.24	6	
24.65	2	a, Ni?	51.42	3	b	44.66	1	a, e, f, g
38.23	4		53.50	1		55.48	1	a, e, f
38.73	1	a, l, g	63.96	1	b, f, g	69.65	1	a, e, f, g
44.60	1	a, f	66.37	1	f	7879.84	1	a, e, f, g
68.42	5	a	70.16	1	f	7912.85	1	f
71.88	1		76.38	1	f	37.19	9	
83.38	1		82.89	1		41.09	2	f
86.73	1		86.41	4		45.91	7	

TABLE 4.—The Arc Spectrum of Iron—Continued

λ I. A.	I	Remarks	λ I. A.	I	Remarks	λ I. A.	I	Remarks
55.81	1	a, b, e, f	8611.73	3	f	25.55	1	
59.21	1	a, b, e, f, g	16.09	1	f, g	42.32	1	a
94.48	1	f	21.55	2	f, g	46.54	1	
7999.00	6		61.85	6		58.49	3	
8024.50	1	a, e, f	74.69	3	f	9259.17	1	a
28.31	1		88.58	7	f	9307.84	1	a
46.08	5		8699.43	1	f, g	18.09	1	
47.60	1	e, f, g	8710.28	1	f, g	24.07	1	a
75.13	1	e, f, g	13.15	1	f, g	43.23	1	a
80.62	1	e, f	57.12	2	f	44.64	1	
85.19	5		63.97	2	f	50.52	2	
8096.85	1	e, f, g	84.39	1	a, e, f, g	54.93	1	a
8133.38	1	a, e, f, g	90.55	1	a, e, f, g	59.36	1	
45.47	1	a, e, f, g	8793.37	2	f	62.29	1	
49.59	1	a, e, f, g	8804.55	1	f, g	72.82	1	
79.03	1	a, e, f, g	24.18	6		9382.83	1	a
86.80	2	e, f, g	38.35	2	g	9401.03	1	
8198.95	2		46.67	1	a, e, g	14.12	1	
8207.75	1		8866.94	3		9443.88	1	a
20.41	7		8919.83	1	e, g	9507.39	1	a
32.33	2		29.02	1	e, g	13.22	1	
39.09	1	e, f, g	45.13	1	g	9569.85	1	
48.09	3	d, e, g	75.33	1	g	9649.85	1	a
74.28	1	f, g	8999.52	4		9653.14	1	
75.91	1	f, g	9012.05	1		9738.69	1	
8293.47	2	f, g	24.26	1	e	9765.53	1	a
8327.04	8		62.29	1	a	9961.23	1	a
31.94	6		70.39	1	e	9978.67	1	a
39.41	4	f	79.64	4	e	10 025.39	.....	
60.79	2	f	80.58	1	e	026.24	.....	a
65.61	2		88.21	4		057.38	.....	
87.74	8		9089.40	4		085.45	.....	
95.10	1	a, f, g	9100.48	2	e	222.02	.....	a
98.27	1	a, f, g	03.66	1	a, e	234.11	.....	
8399.86	1	a, f, g	16.18	1	e	244.35	.....	
8401.42	1	a, f, g	17.17	1	e	246.24	.....	a
22.95	1	a, f, g	18.85	4		257.18	.....	a
24.14	1	a, f, g	21.12	1	a	293.46	.....	
39.58	3	b, f	46.08	1		331.63	.....	a
46.42	1	f, (oxygen)	47.94	1		370.48	.....	a
68.35	7		55.84	1	a	374.52	.....	
71.75	1	a, f	56.93	1	a	375.69	.....	a
8497.00	2	f	60.32	1		396.35	.....	
8514.01	3		64.44	1		478.42	.....	
15.08	2	f	73.48	1		488.09	.....	
26.66	2	f	9183.85	1	a	510.37	.....	
82.20	2	f	9209.99	2		553.06	.....	
92.97	1	f, g	14.42	1		10 689.33	.....	
8598.79	1	f, g	17.55	1				

Wave lengths in the arc spectrum of cobalt are given in Table 5 of which the arrangement is the same as that of Table 4. No intensities are assigned to the lines beyond 10 000 A for reasons stated above, although it is to be noted that the cobalt lines in the infra-red are relatively much stronger than the iron lines in the same region.

The red region of the cobalt arc spectrum has been measured by Stüting [8] whose lines are included between the wave lengths 5905 A and 7054 A. A number of his lines were not measured by us, and vice versa. Lines in our table not given by Stüting are specially designated. Lines of impurities, chiefly iron, copper, chromium, nickel, and manganese have been eliminated as far as possible.

Three lines 7771 A, 7774 A, and 7775 A deserve special remark. These lines are given by Meggers [9] in his table of copper lines. We have since observed them not only in the cobalt spectrum but also in the spectra of iron, nickel, silicon, and copper. The mean values of their wave lengths derived from all our measurements, including those not yet published, are 7771.928 A, 7774.138 A, and 7775.433 A. These lines constitute the well-known triplet which, according to Runge and Paschen,[10] belongs to the principal triplet series of oxygen. The chief interest here lies in the fact that they appear among the arc lines of various metals. They have been observed as absorption lines in the solar spectrum by St. John [11] and by Meggers.[12] In this connection, attention is called to the wave length given as 8446.42 A in Table 4 ("The Arc Spectrum of Iron"). This wave length represents a strong line in the spectrum of oxygen as observed by Runge and Paschen.[13] It also exists as an absorption line in the spectrum of the sun,[14] and it was found in the spectrum of the copper arc [15] in air.

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[8] Zeit. für Wiss. Phot., 7, p. 73; 1909.
[9] This Bulletin, 14, p. 371; 1917.
[10] Wied. Annalen, 61, p. 41; 1897.
[11] See Abbot, The Sun, p. 92; 1911.
[12] Unpublished work on the solar spectrum.
[13] Wied. Annalen, 61, p. 641; 1897.
[14] Unpublished work on the solar spectrum.
[15] This Bulletin, 14, p. 371; 1917.

TABLE 5.—The Arc Spectrum of Cobalt

[In the column headed "Remarks" the letters have the following significance: a=measured only once b=broad; d=perhaps double; g?=perhaps ghost; h=hazy or diffuse; and s=not given by Stüting (5935; A to 7054 A)]

λ I. A.	I	Remarks	λ I. A.	I	Remarks	λ I. A.	I	Remarks
5503.23	1	a	34.25	1	a	90.46	1	
08.29	1	a	36.52	1	a	91.89	10	
15.93	4		37.95	2		93.48	1	
23.27	8		39.59	1	a	95.79	2	a, s
24.93	7		40.99	2		5996.78	5	Ni?
27.19	1	a	43.30	1	a, b	6000.70	8	
28.77	1	a	50.96	3		02.48	3	
30.76	8		52.89	2		05.02	3	
33.09	1	a	53.99	1	a	06.31	8	
36.45	1	a	60.39	1	a	07.67	6	
45.85	6		68.71	1	a	11.43	3	
46.96	3		70.37	6		13.62	3	
58.83	4		74.33	3		15.34	3	
63.69	1	a	82.09	5	Cu?	29.89	2	
65.87	1	a	90.02	4		49.05	10	
73.79	1	a	93.09	1	a	51.35	1	a, s
75.97	1	a	5793.92	1	a, Fe?	58.27	4	
78.78	1	a Ni?	5806.34	1	a	70.61	7	
81.28	2	a	09.39	1	a	82.49	10	
89.27	1	g?	18.09	2	a	83.37	2	a
90.72	8		26.30	4		86.68	7	
5594.79	2		30.05	7		6093.15	6	
5602.40	1	a	33.44	1	a	6100.76	5	
06.83	2	a	34.59	2	a	03.33	1	s
15.70	2		46.57	3		05.49	4	
16.00	2		76.06	3		07.93	9	
22.72	1	a	77.42	3		14.26	1	s
27.84	2	a	78.03	2		17.00	6	
31.69	1		81.05	3		22.68	10	
36.11	6	b	83.42	3		25.74	1	s
37.76	5		86.52	1	a	28.26	3	
40.04	2		90.48	7		29.15	3	
42.98	4		96.02	1	a	30.41	1	
47.20	8		5898.77	1	a	32.44	3	
51.70	4		5905.59	3		43.78	4	
54.14	1	a	15.55	8		46.38	3	
56.10	1	a	16.88	1	a	51.22	2	s
59.07	4		22.35	1		58.53	2	
63.88	1	a	23.13	1		60.04	1	s
69.83	1	a	33.53	1	a, b, h, s	68.86	1	
75.39	3		35.38	7		71.43	1	s
76.49	2		40.49	1		75.08	2	
79.57	3		46.51	7		81.00	5	
84.69	1	a	51.73	2	a	81.90	1	s
86.96	3		53.81	1	s	88.99	7	
88.51	3		63.39	1	a, s	93.58	6	
5696.75	1	a	65.02	3		6197.83	2	
5703.03	2		65.57	2		6203.50	5	
06.07	3		82.01	3		05.50	3	
20.80	1	a	83.36	3		08.75	1	
30.45	1	a	84.25	10		11.15	8	
33.28	1	a	89.58	1		22.32	1	

TABLE 5.—The Arc Spectrum of Cobalt—Continued

λ I. A.	I	Remarks	λ I. A.	I	Remarks	λ I. A.	I	Remarks
23.43	6		47.00	2		56.50	2	s
28.45	1	s	50.24	10		58.08	2	
30.98	7		51.14	5		67.60	4	Ni?
32.45	5		55.03	10		71.05	10	
37.13	2		63.02	5		78.06	1	s
42.48	2	s	70.16	3		84.89	4	
46.42	2		74.57	5		89.28	3	s
47.26	5		77.93	9		91.14	1	s
49.50	6		90.33	7		92.35	1	s
50.80	1	s	6496.18	1	a	6799.39	2	s
53.99	3		6502.29	1	a, s	6807.43	1	s
57.56	10		04.25	4		09.01	5	
62.84	4		08.76	4		14.99	10	
65.97	1		17.06	3		19.57	3	s
71.40	10		28.63	1		26.99	2	b, s
73.06	7		35.16	3		29.92	1	s
75.16	4		38.40	1	b, h, s	38.20	3	s
76.62	5		40.64	1		45.66	2	s
78.19	1		51.45	6		46.99	3	s
82.66	10		54.57	3		58.44	5	s
91.89	3		63.42	9		64.94	3	s
6296.96	2		67.10	2	s	72.42	7	
6302.50	1	a, s	79.29	8		6878.50	2	s
11.29	7	s	88.02	1	s	6901.51	2	s
13.07	6		91.80	3		06.39	1	s
14.50	7		6595.91	9		08.11	5	s
15.76	1		6610.78	1	a, s	10.02	1	s
20.35	10		14.52	1	a, s	10.84	2	s
22.94	2		17.21	10	d	13.31	1	a, s
33.68	1		20.01	1		13.98	1	s
37.98	3		23.70	7		22.23	2	s
40.82	4		32.42	8	s	37.85	7	
47.72	10		35.12	4	Ni?	46.33	2	s
51.37	6		38.40	1	s	48.43	1	a, s
52.80	2		43.78	3	Ni?	50.99	1	a, s
54.80	1	a, b, s	45.33	2	s	72.70	1	a, s
66.20	1	b, s	49.97	3		77.02	1	s
68.86	1	a, s	52.32	3		78.50	2	b, s, Cr?
74.53	1		63.68	2		88.24	1	s
81.86	1	a, b, s	65.28	2		6997.30	7	s
84.49	2	s	72.96	2		7004.82	5	
86.68	6		78.84	6		15.13	2	s
95.19	7		80.35	1		16.65	10	
6395.52	4		82.30	1	b, s	27.86	8	
6403.63	1	s	84.05	3		32.56	4	s
07.36	2		84.88	3		42.61	2	s
08.39	2		6692.89	2	s	46.90	1	a, s
17.79	7		6700.99	1	s	52.84	10	
21.71	5		03.94	3		54.08	8	
25.12	4		12.70	3	s	55.94	3	
29.97	7		17.61	3		57.91	2	
30.28	1		20.97	2	s	58.65	1	
35.17	1	s	22.82	2	b, s	65.43	1	
39.83	2		42.12	3	s	70.45	4	
44.75	6		51.15	1	s	79.21	2	

TABLE 5.—The Arc Spectrum of Cobalt—Continued

λ I. A.	I	Remarks	λ I. A.	I	Remarks	λ I. A.	I	Remarks
84.99	10		33.52	5		7885.21	2	
94.64	4		54.04	8		7907.14	1	a
7097.84	1		59.68	3		08.75	10	
7101.77	1		61.08	4		12.90	1	a
02.57	4		64.98	5		19.50	2	
13.74	9		78.34	1	a	26.59	8	
14.09	1	a	80.95	1		57.77	3	
17.91	2		86.72	4		60.55	2	
22.26	5	Ni?	88.71	1	a	62.40	1	a
24.45	5		90.60	6		66.12	2	
34.37	8		7594.18	1		80.48	1	a
54.71	8		7600.11	1	a	84.22	1	a
59.23	8		04.30	1		87.38	7	
73.37	1		06.30	1		96.83	1	
85.63	1	Cr?	10.29	6		7998.12	1	
7193.63	8		16.13	1	a	8007.34	10	
7202.07	1	a	18.66	1		13.02	2	
04.54	1	a	34.56	5		16.59	1	
17.36	2		37.63	4		17.88	1	
21.06	1	a	41.43	1		22.15	7	
27.16	1	a	48.19	4		24.75	4	
50.09	3		64.89	1	a	29.29	7	
63.57	2		85.65	1		31.07	1	a
85.29	7		95.97	2		32.41	1	
7297.39	1	a	7698.95	1	a	37.63	1	
7305.35	1	a	7701.88	2		41.33	2	
07.86	1		04.90	2		43.33	8	
15.72	3		12.68	9		50.60	1	
41.61	1		25.92	2		53.50	1	
46.32	1	a	28.59	1	a	56.03	8	
49.68	1		34.25	6		62.98	2	
51.55	1		35.47	1		66.50	7	
53.48	2		43.27	5		80.23	5	
54.61	6		64.07	1		82.60	1	
65.77	1		71.95	1		85.47	2	
88.66	7		74.16	1	Oxygen triplet	8094.03	10	
7398.72	1		75.43	1		8112.13	1	a
7406.23	1		79.06	1	a	14.03	1	
14.64	1		86.63	1		16.43	7	
17.40	8		7794.15	1	a	37.10	5	
29.03	2		7809.25	1		40.42	2	
37.15	4		10.39	1		50.23	2	
43.48	2		17.15	1	a	52.03	6	
57.43	8		18.25	1	a	54.31	1	
71.21	1		22.12	1	a	60.68	2	
74.35	1	a	38.18	8		67.97	2	
77.28	1		40.05	7		89.29	1	a
78.78	1		43.61	1		8193.05	8	
84.00	1	a	55.88	7		8208.67	8	
89.41	3		59.41	1		43.38	1	a
7495.09	1		66.10	1	a	46.57	1	a
7502.74	2		69.92	6		59.10	1	a
15.28	1		71.43	6		69.39	8	
24.07	1	a	73.36	1		72.34	1	
26.32	1		77.44	2		75.55	1	

TABLE 5.—The Arc Spectrum of Cobalt—Continued

λ I. A.	I	Remarks	λ I. A.	I	Remarks	λ I. A.	I	Remarks
83. 49	5		50. 74	10		020. 68		a
96. 85	5		56. 63	1	a	189. 16		a
8299. 02	5		62. 69	2	Ni?	194. 38		a
8301. 44	1		66. 96	1		206. 05		
12. 92	2		70. 79	4		210. 83		
15. 32	2		78. 30	1		213. 32		
18. 55	1		86. 25	1	a	236. 37		
31. 70	2		8888. 70	2		272. 89		a
34. 71	1	a	8904. 65	8		284. 63		a
42. 66	4		26. 24	10		303. 08		b
45. 59	2		39. 20	1		310. 95		a
72. 82	10		58. 46	6		324. 71		Fe, sec. ord?
78. 37	7		8972. 91	1		332. 47		
8379. 54	3		9025. 96	1	a	339. 09		
8409. 03	1		32. 70	1	a	366. 64		a
54. 71	1		37. 92	8		368. 94		a, b, h
78. 45	2		9095. 36	6		379. 28		
8489. 41	2		9178. 03	1		435. 30		a
8504. 54	1		9280. 71	1	a	505. 88		
13. 48	1		9344. 89	1		557. 90		
49. 04	1	a, Cr?	9357. 02	10		570. 55		a
59. 04	2		9474. 77	1		616. 54		
60. 01	1	a	9530. 99	1	a	838. 19		
69. 72	2		36. 23	1		885. 87		
74. 49	3		44. 52	2		10 908. 52		
75. 32	4		9597. 89	2		11 000. 41		
86. 71	3		9616. 55	1		012. 76		a
89. 70	3		9619. 41	1	a	231. 24		Fe, sec. ord?
8596. 09	1		9745. 98	1		265. 64		a
8648. 81	1	a	9818. 39	2		275. 45		a
55. 76	1	a	34. 19	1		289. 33		
58. 18	1	a	42. 06	1	a	293. 46		a
61. 04	2		69. 23	2		316. 92		
8675. 02	1		70. 84	1		340. 76		
8733. 22	1		9892. 90	1		453. 42		a
8750. 13	1		9914. 12	3		601. 93		a
8819. 15	10		37. 98	1		610. 54		a, Ni, sec. ord?
35. 22	8		54. 24	1		11 623 63		a
37. 83	2		9983. 20	1				
38. 41	2	a	10 017. 97					

Table 6 contains the wave lengths found in the arc spectrum of nickel. Stüting [16] and Hamm [17] have measured a portion of this spectrum in the red but recorded only three lines (6842, 6914, and 7122) whose wave lengths exceeded 6772 A. It is hoped that most of the lines due to iron, cobalt, copper, chromium, and manganese have been omitted from Table 6. As in the preceding tables no intensities are assigned to the lines whose wave lengths exceed 10 000 A.

[16] Zeit. für Wiss. Phot., 7, p. 73; 1909.
[17] Zeit. für Wiss. Phot., 13, p. 105; 1913.

TABLE 6.—The Arc Spectrum of Nickel

[The letters in the "Remarks" column have the following significance: a=measured only once; b=broad; d=perhaps double; g?=perhaps ghost; h=hazy or diffuse; v=shaded to violet; l=shaded to red; s=not given by Stüting (5892 A to 6772 A); and m=not given by Hamm (5504 A to 6772 A)]

λ I. A.	I	Remarks	λ I. A.	I	Remarks	λ I. A.	I	Remarks
5504.14	1		12.21	3		6414.63	5	
09.97	4		25.73	1	m, s	21.45	5	s
14.80	1	m	39.35	1	m	24.93	4	s
21.44	1	a, m	53.71	5		32.06	1	a, m, s
37.11	1	a, m	86.36	9		51.59	2	m, s, Fe?
53.74	3		90.27	1	a, m, s	52.77	1	m, s
78.71	5		6095.38	1	m	55.06	1	m, Co?
87.91	5		6105.72	1	m, s	6482.83	6	
89.36	3		08.13	5		6502.27	2	Co?
92.21	6	d	10.94	8	v	32.90	5	
5593.74	5		12.86	1	a, m, s, g?	63.42	1	a, m, s
5600.09	4		16.13	8		76.34	2	
07.05	1	a, m	18.06	1	m, s	80.16	4	
14.81	5		19.80	3		86.33	6	
25.27	6		28.96	3		92.52	6	
28.37	3		30.18	4		6598.53	6	
31.72	1	m	34.03	1	m	6610.82	1	a, m, s
37.19	5		41.96	1	s	21.24	1	m, s
38.82	1	m	63.31	8	v	29.67	1	m, s
41.80	4	m	70.55	3		35.16	6	s
43.13	2		75.46	9		43.67	8	
49.75	3		76.83	10		47.80	1	a, m, s
64.06	5		80.06	2	m	61.45	3	m
69.99	3		83.14	1	a, m, s	6690.82	2	m, s
82.21	7		83.92	1		6700.90	1	a, m, s
91.52	1	Fe? m	86.80	6		42.64	1	m, s
5694.95	7		91.24	7		59.41	1	m, s
5703.65	1	m	6198.62	1	m, s	67.80	10	
09.57	7		6204.65	5		72.40	9	
11.92	6		23.95	6		82.43	2	
15.11	6		30.07	4		91.19	1	
48.35	3		56.46	6		6798.44	1	
49.28	1	m	58.60	3		6813.60	3	
54.67	6		59.68	3		42.10	6	
60.87	5		71.84	1	m, s	50.46	2	
80.77	1	m	6272.69	1		61.20	3	
96.10	2	m Fe?	6300.31	1	a, s	70.13	3	
5798.20	1	m	14.63	9	v	72.38	1	a
5805.20	8	v	16.61	1	h, m, s, g?	6876.77	3	
31.62	6		22.15	4		6901.89	1	
47.02	3		27.60	4		02.83	2	Fe?
57.77	8		39.17	8		14.60	7	
63.97	2	m	50.39	1	m, s	28.36	2	
5892.88	6		60.75	6		55.10	5	
5906.50	2		64.58	1		6973.51	2	
23.98	2		66.41	6		7001.55	4	
73.66	1	a, m, s	70.45	2		04.32	1	h, a
96.80	4	Co? s	75.32	1	m, s	08.56	1	h, a
97.61	4		78.22	7		16.51	1	Co?
5998.86	1	s, m	80.99	1	m, s	23.82	1	
6007.33	3		6384.70	6		24.76	8	

TABLE 6.—The Arc Spectrum of Nickel—Continued

λ I. A.	I	Remarks	λ I. A.	I	Remarks	λ I. A.	I	Remarks
28.79	2		14.51	6		7994.50	2	
30.10	5		19.28	2		8012.94	2	
32.16	1	a	22.34	9		28.33	2	Fe?
34.42	4		33.40	3		34.55	1	a
37.21	2		38.53	1	a	8095.93	1	a
49.56	1	b	53.92	1	a	8248.17	1[4]	
63.05	4		81.49	5		8417.22	2	
63.52	2		7488.72	2	1	8501.81	2	
67.38	2		7501.81	1	b	8506.43	1	
68.27	1		21.09	2		8637.05	2	
82.22	1	h, a	22.87	8		8702.46	2	
7095.47	4	Fe?	25.18	8		8809.46	3	
7101.98	1		34.57	1	a	62.60	4	
10.98	6		37.27	1	h	8877.07	1	a
22.31	10		45.69	2		8965.96	2	
26.73	2		47.65	1	a	8968.16	2	
29.15	1	a	52.25	2	b	9005.05	1	a
41.55	1		55.67	9		11.97	1	a Fe?
46.69	1		59.63	3		58.55	2	
50.81	2		67.35	1	h, a	76.85	1	a
67.04	4		7574.10	7		78.67	2	
70.10	2		7610.02	3		9085.15	1	a
73.70	2		17.02	10		9106.33	3	
82.06	9		19.24	9		9150.64	1	a
7197.07	7		24.75	2		9296.42	1	
7220.74	3	b	27.39	1	a	9470.23	1	
25.13	1	a	43.74	1	a	9519.99	2	
26.97	1	a	7657.28	3		9675.56	1	a
56.72	1	a	7709.05	1	a	9966.19	3	
61.94	8		11.39	1	a	9989.94	1	
66.14	4		14.27	8		10 049.85	.....	a
86.59	2		15.64	7		346.08	.....	
90.88	1	a	27.68	10		368.08	.....	a
91.30	8		35.99	1	a	386.22	.....	
7297.75	3		48.94	10		526.76	.....	a
7309.57	2		88.95	6		530.09	.....	a
27.69	4		7797.66	8		551.83	.....	a
33.57	2	Fe?	7826.84	4		572.74	.....	a
48.49	1	a	55.05	3	h	598.38	.....	a
51.35	3	Fe?	61.10	4		634.31	.....	a
81.93	5		63.70	5		658.57	.....	a
85.23	7		69.81	1	a	661.66	.....	a?
86.24	7		7890.18	3		832.93	.....	a
7393.67	10		7917.47	7		839.80	.....	a?
7401.12	4		53.13	1	a	10 843.17	.....	a
09.35	9		60.77	1	a			

The large number of lines photographed in the infra-red spectra of these arcs shows the importance of using and developing photographic methods as far as possible. The photographic method has great advantages over the radiometric method in being able to record fainter lines and resolve complex or close lines in addition to allowing greater possible accuracy in the wave-

length measurements. In the spectral region in which our photographs overlap radiometric observations, for the elements in question, our tables contain from 5 to 10 times as many lines as were observed by means of the radiometer. However, for waves longer than about 10 000 A the sensitivity of the bolometer so enormously exceeds that of photographic plates at the present time that it is necessary to rely upon the radiometer for practically all spectroscopic data. Extensive and careful investigations in the region to which both methods apply should assist in removing some of the difficulties and uncertainties in studying the longer waves.

V. SUMMARY

The arc spectra of iron, cobalt, and nickel were photographed in the red and infra-red regions on plates stained with pinacyanol and dicyanin. A large concave grating was used, and exposures up to 10 hours duration registered many lines with wave lengths greater than 10 000 A, or 1 micron. In the arc spectrum of iron, 298 lines were measured between the wave-length limits 6750 A and 10 689 A; 606 lines were measured between 5503 A and 11 623 A in the arc spectrum of cobalt; and 290 lines between 5504 A and 10 843 A in the arc spectrum of nickel. As far as possible, impurities were eliminated and lines assigned to their proper element. Four lines due to oxygen were found in these arc spectra and are included in the wave-length tables. These results demonstrate that an invisible long-wave interval as large as the entire visible spectrum is accessible to photography with dicyanin-stained plates. The incompleteness of spectroscopic data for these longer light waves invites extensive application of this method of spectrum photography.

WASHINGTON, *February 8, 1918.*

NOTE (April 16, 1919).—Since the above article was written, a number of the lines of wave length greater than 9000 A in the foregoing tables have been found to be "ghosts" of the type discovered by Lyman. A preliminary investigation shows that they may be calculated by multiplying the parent lines (lines ranging in intensity from 7 to 10) by the factors 1.39931, 1.40267, 1.59732, and 1.60066, respectively. A study of the false spectra produced by gratings is being made and will be published later.